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Method 5702—Federal Test Method Standard No. 791b

Standard Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using Disk Electrodes[1]

This standard is issued under the fixed designation D 877; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This method has been approved for use by agencies of the Department of Defense and for listing in the DoD Index of Specifications and Standards.

1. Scope

1.1 This test method covers a referee and a routine procedure for determining the dielectric breakdown voltage of insulating liquids. These procedures are applicable to liquid petroleum oils, hydrocarbons, and askarels commonly used as insulating and cooling mediums in cables, transformers, oil circuit breakers, and similar apparatus. The referee procedure, with modifications, is suitable for testing silicone fluids (see Methods D 2225). The referee procedure is also suitable for testing alkylbenzenes. The suitability of either the referee or the routine procedure for testing liquids having viscosities exceeding 900 cSt (mm^2/s) (5000 SUS) at 40°C (104°F) has not been determined.

1.2 This test method is recommended for acceptance tests on unprocessed insulating liquids received from vendors in tank cars, tank trucks, and drums. It may also be used for the routine testing of liquids from power systems apparatus rated 230 kV and below.

1.3 This test method is not recommended for testing filtered, degassed, and dehydrated oil prior to and during the filling of power systems apparatus rated above 230 kV, or for testing samples of such oil from apparatus after filling. Test Method D 1816 is more suitable for, and is recommended for, testing such oils.

1.4 Both the SI and inch-pound units are equally acceptable.

1.5 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 484 Specification for Hydrocarbon Drycleaning Solvents[2]

D 923 Methods of Sampling Electrical Insulating Liquids[3]

D 1816 Test Method for Dielectric Breakdown Voltage of Insulating Oils of Petroleum Origin Using VDE Electrodes[3]

D 2225 Methods of Testing Silicone Fluids Used for Electrical Insulation[2]

2.2 *Institute of Electrical and Electronics Engineers Standard:*

No. 4 Measurement of Voltage in Dielectric Test[4]

3. Significance and Use

3.1 The dielectric breakdown voltage of an insulating liquid is of importance as a measure of the liquid's ability to withstand electric stress without failure. It serves to indicate the presence of contaminating agents, such as water, dirt, moist cellulosic fibers, or conducting particles in the liquid, one or more of which may be present in significant concentrations when low dielectric breakdown values are found by test. However, a high dielectric breakdown voltage does not indicate the absence of all contaminants; it may merely indicate that the concentrations of contaminants that are present in the liquid between the electrodes are not large enough to deleteriously affect the average breakdown voltage of the liquid when tested by this method. See Appendix X1.

4. Apparatus

4.1 *Transformer*—The desired test voltage may be most readily obtained by a step-up transformer energized from a variable low-voltage commercial power frequency source. The transformer and controlling element shall be of such size and design that, with the test specimen in the circuit, the crest factor (ratio of maximum to mean effective) of the 60-Hz test voltage shall not differ by more than ±5 % from that of a sinusoidal wave over the upper half of the range of test voltage. The crest factor may be checked by means of an oscilloscope, a sphere-gap, or a peak-reading voltmeter in conjunction with a root-mean-square voltmeter. Where the wave form cannot be determined conveniently, a transformer having a rating of not less than ½ kVA at the usual breakdown voltage shall be used. Transformers of larger kilovolt-ampere capacity may be used, but in no case should the short-circuit current in the specimen circuit be outside the range of 1 to 10 mA/kV of applied voltage. This limitation of current may be accomplished by the use of a

[1] This test method is under the jurisdiction of ASTM Committee D-27 on Electrical Insulating Liquids and Gases and is the direct responsibility of Subcommittee D27.05 on Electrical Test.

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[2] Discontinued; see *1984 Annual Book of ASTM Standards*, Vol 05.01.

[3] *Annual Book of ASTM Standards*, Vol 10.03.

[4] Available from The Institute of Electrical and Electronics Engineers, Inc., 345 E. 47th St. New York, NY 10017.

suitable external series resistor or by the designed reactance of the transformer.

4.2 *Circuit-Interrupting Equipment*—The test transformer primary circuit shall be protected by an automatic circuit-breaking device capable of opening in 3 cycles or less on the current produced by breakdown of the test specimen. A 5-cycle breaker may be used if the short-circuit current as described in 4.1 does not exceed 0.2 A. The current-sensing element that trips the circuit breaker should operate when the specimen-circuit current is in the range of 2 to 20 mA. A prolonged flow of current at the time of breakdown causes carbonization of the liquid and pitting and heating of the electrodes, and thereby increases the electrode and test cup maintenance and time of testing.

4.3 *Voltage-Control Equipment*—The rate of voltage rise shall be 3 kV/s ± 20 %. Voltage control may be secured by a motor-driven variable-ratio-autotransformer. Preference should be given to equipment having an approximately straight-line voltage-time curve over the desired operating range. Motor drive is preferred to manual drive because of the difficulty of maintaining a reasonably uniform rate-of-voltage rise with the latter. The rate-of-voltage rise may be calculated from measurements of the time required to raise the voltage between two prescribed values. When motor-driven equipment is used, the speed control rheostat should be calibrated in terms of rate-of-voltage rise for the test transformer used.

4.4 *Voltmeter*—The voltage shall be measured by a method that fulfills the requirements of IEEE Standard No. 4, giving rms values, preferably by means of:

4.4.1 A voltmeter connected to the secondary of a separate potential transformer, or

4.4.2 A voltmeter connected to a well-designed tertiary coil in the test transformer, or

4.4.3 A voltmeter connected to the low-voltage side of the testing transformer if the measurement error can be maintained within the limit specified in 4.5.

4.5 *Accuracy*—The combined accuracy of the voltmeter and voltage divider circuit should be such that measurement error does not exceed 5 % at the rate-of-voltage rise specified in 4.3.

5. Electrodes

5.1 The electrodes shall be polished brass disks 25 mm or 1 in. in diameter, and at least 3 mm or ⅛ in. thick, with square edges.

6. Test Cup

6.1 A test cup having rigidly mounted electrodes with parallel faces and axes in a coincident horizontal line shall be used. The cup shall be constructed so that no part of it is less than 13 mm or ½ in. from any part of the test electrode disk. The total leakage and charging current of the cup, when filled with a good grade of oil, shall be less than 200 µA at 20 kV, 60 Hz. It shall be made of a material of high dielectric strength, and shall not be attacked by any of the cleaning or test liquids. It shall not absorb moisture or the cleaning and test liquids. The top of the cup should be at least 25 mm or 1 in. above the top of the electrodes. The cup shall be designed to permit easy removal of the electrodes for cleaning and polishing, and to permit easy adjustment of the gap spacing.

7. Adjustment and Care of Electrodes and Test Cup

7.1 *Electrode Spacing*—The spacing of the electrodes during tests shall be 2.5 mm or 0.100 in. This shall be determined with a standard round gage of 2.5 ± 0.01 mm or 0.100 ± 0.0005 in., or flat steel "go" and "no-go" gages having thicknesses of 2.49 and 2.51 mm or 0.0995 and 0.1005 in., respectively. The spacing shall be rechecked following any polishing, wiping, or cleaning operation in which the cup is disassembled or the electrodes disturbed, and at the beginning of each day's testing.

7.2 *Cleaning*—The electrodes and the cup shall be wiped clean with dry, lint-free tissue paper or a clean dry chamois. It is important to avoid touching the electrodes or the cleaned gage with the fingers or with portions of the tissue paper or chamois that have been in contact with the hands. After adjustment of the gap spacing, the cup shall be rinsed with a dry hydrocarbon solvent, such as kerosine or Stoddard solvent.[5] A low-boiling solvent should not be used as its rapid evaporation may cool the cup, causing moisture condensation. If this occurs, the cup should be warmed slightly to evaporate the moisture before using it. Care shall be taken to avoid touching the electrodes or the inside of the cup after cleaning. After thorough cleaning, the cup shall be flushed with new, dry, filtered liquid of the type being tested, (preferably degassed oil if the cup is being used for testing oils). A voltage breakdown test shall be made on a sample of this liquid in the manner specified in this method. If the breakdown voltage is in the proper range for liquid in this good condition, the test cup shall be considered as properly prepared for testing other samples. If a lower value is obtained, the cup shall again be thoroughly cleaned and the test repeated with a clean dry liquid.

7.3 *Daily Use*—At the beginning of each day's testing, the electrodes shall be examined for pitting and contamination. They should be repolished if pitting is severe. Carbon or dirt should be wiped off, and the gap setting checked. The cup shall be flushed, and tested with a clean dry liquid as described in 7.2.

7.4 *Polishing of Electrodes*—When examination of electrodes shows minor scratching or pitting, the electrodes should be removed from the test cup and polished by buffing with jeweler's rouge using a soft cloth or soft buffing wheel. (Resurfacing may be necessary in order to remove deep pit marks or edge damage.) Care must be taken in resurfacing or in polishing to ensure that the electrode faces remain perpendicular to the axis and that the edges do not become rounded. All residue from the buffing must be removed before the electrodes are reinstalled in the test cup. This can be accomplished by repeated wiping with lint-free tissue paper saturated with a suitable solvent (such as petroleum ether), followed by solvent rinsing or ultrasonic cleaning. After the electrodes have been reinstalled in the test cup, clean and adjust spacing in accordance with 7.1 and 7.2.

7.5 *Storage of Test Cup*—When not in use, the cup, if used for referee tests, shall be stored filled with a new, dry,

[5] See ASTM Specification D 484, for Hydrocarbon Drycleaning Solvents, *Annual Book of ASTM Standards*, Vol 05.01.

filtered liquid of the type being tested, and tightly covered.

8. Sampling

8.1 A sample of the liquid to be tested shall be obtained with the sampling apparatus applicable to the type of liquid as specified in accordance with Methods D 923. The sample shall be taken in a dry, clean bottle that shall be tightly sealed and shielded from light until ready to be tested (Note 1). Prior to starting the test, the sample shall be inspected for the presence of moisture, sludge, metallic particles, or other foreign matter. If the sample shows evidence of free water, the dielectric breakdown test may be waived, and the sample shall be reported as unsatisfactory.

NOTE 1—It is suggested that 2 L of sample be made available when referee tests are to be made, and 1 L of sample be made available when routine tests are to be made.

8.2 The dielectric breakdown voltage of liquids may be seriously impaired by the migration of impurities through the liquid. In order that a representative test specimen containing the impurities may be obtained, the sample container shall be gently inverted and swirled several times before filling the test cup. Rapid agitation is undesirable, since an excessive amount of air may be introduced into the liquid. Immediately after agitation, a small portion of the sample shall be used to rinse the test cup. The cup shall then be filled slowly with the liquid to be tested in a manner that will avoid entrapment of air. It should be filled to a level not less than 20 mm or 0.8 in. above the top of the electrodes. In order to permit the escape of air, the liquid shall be allowed to stand in the cup for not less than 2 min and not more than 3 min before voltage is applied.

NOTE 2—It is impractical to handle liquids having viscosities ranging between 10 and 22 cSt (mm²/s) (60 and 100 SUS) at 100°C (212°F) in the manner outlined in 8.2. When testing high-viscosity liquids in this range, the sample should be allowed to stand until it reaches room temperature, which should not be less than 20°C (68°F). The sample container should not be swirled as prescribed in 8.2, but should be inverted for at least 30 min before the test, and then reinverted and opened just prior to filling the test cup.

9. Test Temperature

9.1 The temperature of the specimen when tested shall be the same as that of the room, but the room temperature shall in no case be less than 20°C (68°F). Testing liquids at temperatures lower than that of the room will give variable and unsatisfactory results.

10. Rate of Rise of Voltage

10.1 Voltage shall be applied and increased from zero at the rate of 3 kV/s ± 20 % until breakdown occurs as indicated by operation of the circuit-interrupting equipment, and the value recorded. Occasional momentary discharges may occur which do not result in operation of the interrupting equipment, and shall be disregarded.

11. Procedure

11.1 *Referee Testing*—When it is desired to determine the dielectric breakdown voltage of a new liquid for referee purposes, one breakdown shall be made on each of five successive fillings of the test cup. The breakdown voltage thus obtained shall be subjected to the criterion for statistical consistency as specified in 11.3. If the five values meet this criterion, their average shall be reported as the dielectric breakdown voltage of the sample. If they do not meet this criterion, one breakdown on each of five additional cup fillings shall be made, and the average of the ten breakdowns shall be reported as the dielectric breakdown voltage of the sample. No breakdown shall be discarded.

11.2 *Routine Testing*—When it is desired to determine the dielectric breakdown voltage of a liquid on a routine basis, five breakdowns may be made on one cup filling with 1-min intervals between breakdowns. The average of the five breakdowns shall be considered the dielectric breakdown voltage of the sample, provided the breakdown values meet the criterion for statistical consistency as specified in 11.3. If the breakdown voltages do not meet this criterion, the contents of the cup shall be discarded, the sample container again gently inverted and swirled, the cup again filled, and five breakdowns made on this second cup filling. The average of the 10 breakdowns shall be considered as the dielectric breakdown voltage of the sample. No breakdown shall be discarded.

11.3 *Criterion for Statistical Consistency*—

11.3.1 Calculate the mean and standard deviation of the five breakdowns as follows:

$$\bar{x} = \frac{1}{5} \sum_{i=1}^{5} x_i \text{ and } s = \sqrt{\frac{1}{2}\left(\sum_{i=1}^{5} x_i^2 - 5\bar{x}^2\right)}$$

where:

$\bar{x}$ = mean of the five individual values,
x_i = ith breakdown voltage, and
s = standard deviation.

If the ratio $s/\bar{x}$ exceeds 0.1, it is probable that the standard deviation of the five breakdowns is excessive, and therefore that the probable error of their average is also excessive.

11.3.2 *Alternative Criterion*—Calculate the range of the five breakdowns (maximum breakdown voltage minus minimum breakdown voltage), and multiply this range by three. If the value so obtained is greater than the next to the lowest breakdown voltage, it is probable that the standard deviation of the five breakdowns is excessive, and therefore the probable error of their average is also excessive.

12. Report

12.1 The report shall include the following:

12.1.1 ASTM designation of the test method used (D 877),

12.1.2 Procedure used, that is, referee test or routine test.

12.1.3 Approximate viscosity of the liquid tested,

12.1.4 Temperature of the liquid and the room at time of test, and

12.1.5 Individual breakdown values and the average breakdown value in any of the following ways that may apply:

12.1.5.1 Five breakdowns, one on each of five cup fillings that meet the criterion of statistical consistency,

12.1.5.2 Ten breakdowns, one on each of ten cup fillings when the first five breakdowns do not meet the criterion for statistical consistency,

12.1.5.3 In routine testing, five breakdowns on one cup filling that meet the criterion of statistical consistency, or

12.1.5.4 When the routine test is employed, five breakdowns on each of two cup fillings when the breakdowns on the first cup filling do not meet the criterion of statistical consistency.

12.1.6 If the sample was observed to contain free water or other contaminants, the report should so indicate, with a statement that the test was not made.

13. Precision and Bias

13.1 The precision of this test method has not been determined. No statement can be made about the bias of this test method because a standard reference material is not available.

APPENDIX

(Nonmandatory Information)

X1. OTHER FACTORS THAT AFFECT THE DIELECTRIC BREAKDOWN VOLTAGE OF INSULATING LIQUIDS AT COMMERCIAL POWER FREQUENCIES

X1.1 The dielectric breakdown voltage of a liquid at commercial power frequencies is also affected by the degree of uniformity of the electric field, the area of the electrodes or volume of the liquid under maximum stress, the length of time for which the liquid is under stress, the temperature of the liquid (especially insofar as it affects the relative saturation level of moisture in solution), gassing tendencies of the liquid under the influence of electric stress, concentration of dissolved gases (especially if saturation levels are exceeded as a result of sudden cooling or decrease in pressure, which may cause the formation of gas bubbles), incompatibility with materials of construction, and velocity of flow. A decrease in dielectric strength of the liquid can have an accentuated effect on the electric creepage strength of solid insulating materials immersed in the liquid.

X1.2 Because of the separate, cumulative, and in some cases, interacting effects of the influences listed above, the average breakdown voltage of a liquid as determined by this test method cannot be used for design purposes. Alternative test procedures that may yield more meaningful indications of the functional dielectric strength of a liquid are under consideration (for example, a step-by-step method of applying voltage, and using the lowest rather than the average value of breakdown voltage obtained in the prescribed number of tests).

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